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SEARCH FOR THE HIGGS BOSON DECAYING INTO TAU PAIRS

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A search for the Standard Model Higgs Boson decaying into τ pairs is performed using events recorded by the CMS experiment at the LHC in 2011 and 2012. An excess of events is observed over a broad range of Higgs mass hypotheses, with a maximum local significance of 2.93 standard deviations at $m_H = 120 \text{ GeV}/c^2$. The excess is compatible with the presence of a standard-model Higgs boson of mass $125 \text{ GeV}/c^2$.

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1. Introduction

We present a search for the Standard Model Higgs Boson decaying into tau-pairs in the invariant mass region $110\text{--}145 \text{ GeV}/c^2$ performed using events recorded by the CMS experiment at the LHC in 2011 and 2012 corresponding to an integrated luminosity of 4.9 fb^{-1} at a centre-of-mass energy of 7 TeV and 19.4 fb^{-1} at 8 TeV. Since July 4th 2012 an experimental observation of a new Boson of a mass around $125 \text{ GeV}/c^2$ and compatible with the Standard Model Higgs Boson hypothesis is established both by the Atlas and CMS collaborations Ref. 2, 3, 4. The observation of the Higgs-like Boson is predominantly based on its couplings to gauge bosons. To seek direct evidence for its fermionic couplings, the search for the Standard Model Higgs Boson decaying into tau-pairs is a distinguished channel to be analyzed with the CMS detector.

2. Analysis Strategy

The search is simultaneously performed in several final states of the decaying di-tau system, henceforth denoted as: $\tau_h\tau_h$, $e\tau_h$, $\mu\tau_h$, $e\mu$ and $\mu\mu$, where τ_h declares the hadronically decaying tau final states. For each final state the events are then divided into several disjoint event categories in order to enhance the overall sensitivity by exploiting the distinct event topologies of the Higgs production processes. Major Higgs production mechanisms considered are processes via gluon fusion, vector

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boson fusion and the vector boson associated production. The dedicated $H \rightarrow \tau\tau$ analyses exploiting the associated Higgs productions (see Ref. 5) are not discussed in detail in this review, however are included in the results in figure 3 and 2.

The most sensitive category is the Vector Boson Fusion (VBF) category where the event topology of Standard Model Higgs production via Vector Boson Fusion is exploited which is characterized by two high p_T jets in the forward regions of the detector. In addition to the event and lepton selection criteria events in the VBF category are required to have two jets with $p_T > 30$ GeV/c and $|\eta| > 4.7$, having an invariant mass of $m_{jj} > 500$ GeV/c², with a separation in the pseudo-rapidity $\Delta\eta_{jj} > 3.5$ and no additional jet with $p_T > 30$ GeV/c in the eta gap between the two corresponding jets.

In addition a 1-Jet category is defined. Events with at least one jet with $p_T > 30$ GeV/c and $|\eta| > 4.7$ are selected in this category, excluding events of the VBF category. The Standard Model Higgs production via gluon fusion dominates the signal contribution in the 1-Jet category.

Further the 0-Jet category is defined for events with no jet with $p_T > 30$ GeV/c and $|\eta| > 4.7$. This category is largely dominated by background processes and is used to constrain the backgrounds in the VBF and 1-Jet categories.

For all categories a b-tagged jet with $p_T > 20$ GeV/c veto is applied to decouple the analysis from the MSSM Higgs search in the di-tau channel.

The background compositions are channel and category dependent with the $Z\gamma^* \rightarrow \tau\tau$ processes representing typically the most dominant contributions over $t\bar{t}$, W +Jets, $Z \rightarrow \ell\ell$, QCD multijet-events and di-boson productions. To further reduce the various backgrounds additional topological event selection criteria depend on the final state are defined.

For the $e\mu$ final state the $t\bar{t}$ background is significantly reduced with selection criteria on $D_\zeta = p_\zeta - 0.85 \cdot p_\zeta^{vis} > -20$ GeV/c, where ζ is the bisector of the two

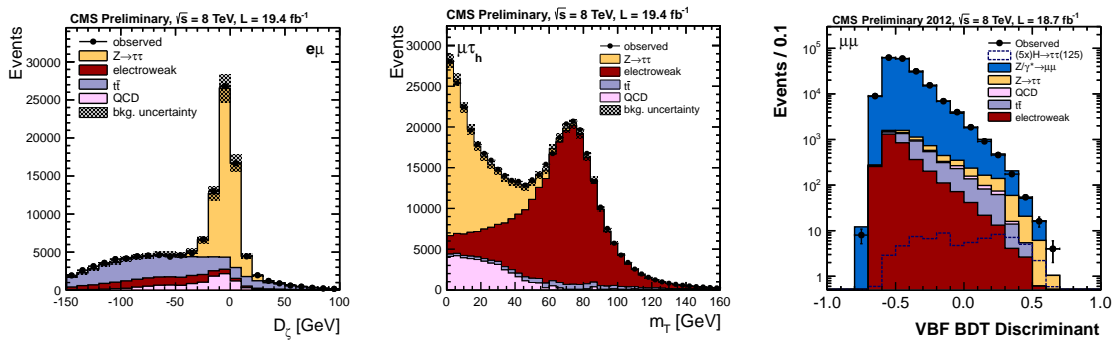


Fig. 1. Left: Distribution of the P_ζ variable in the $e\mu$ channel. Middle: Distribution of the m_τ variable in the $\mu\tau_h$ channel. Right: Distribution of the BDT discriminant in $\mu\mu$ channel as an example in the VBF category.

leptons, $p_\zeta = \vec{p}_{T,1} \cdot \hat{\zeta} + \vec{p}_{T,2} \cdot \hat{\zeta} + \vec{E}_T^{miss} \cdot \hat{\zeta}$ and $p_\zeta^{vis} = \vec{p}_{T,1} \cdot \hat{\zeta} + \vec{p}_{T,2} \cdot \hat{\zeta}$. D_ζ is a measure of how collinear the missing transverse energy vector is with the transverse momentum of the di-lepton system (see figure 1 (left)).

For the $e\tau_h$ and $\mu\tau_h$ final states the W+Jets background is reduced by selection criteria on the transverse mass variable $m_T = \sqrt{2p_T E_T^{miss}(1 - \cos(\Delta\phi))}$ (see figure 1 (middle)).

For the $\mu\mu$ final state the overwhelming $Z/\gamma^* \rightarrow \mu\mu$ background is reduced by selection criteria on dedicated multivariate Boosted Decision Trees in each category. (see figure 1 (right)).

3. Results

The observed and expected 95% CL exclusion limit on the Standard Model Higgs Boson production rate is derived by a combined fit on the reconstructed di-tau mass $m_{\tau\tau}$ in each category for each channel and shown in figure 2 (right). For the $\mu\mu$ final state the 2 dimensional distribution of $m_{\tau\tau}$ versus the invariant mass of the two muons is used. Figure 2 (left) shows the combined $m_{\tau\tau}$ distribution obtained after summing up the $m_{\tau\tau}$ distribution of each category of the $\tau_h\tau_h$, $e\tau_h$, $\mu\tau_h$ and $e\mu$ final states weighted by the ratio of the expected signal and background yields.

An excess of the observed limit when compared to the background-only hypothesis is found and the local p-value and significance of this excess as a function of the Higgs mass is shown in figure 3 (left). A maximum significance of 2.93 standard deviations is observed for a Higgs mass of $m_H = 120 \text{ GeV}/c^2$ and a significance of 2.85σ at $m_H = 125 \text{ GeV}/c^2$ compared to the Standard Model expectation of 2.63σ . The signal strength for m_H is measured to be 1.1 ± 0.4 times the Standard Model

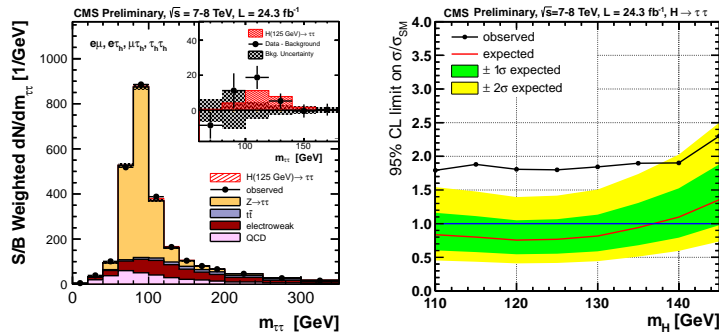


Fig. 2. Left: Combined $m_{\tau\tau}$ distribution of $\tau_h\tau_h$, $e\tau_h$, $\mu\tau_h$ and $e\mu$ final states weighted by the ratio of the expected signal and background yields in each category. Right: Observed and expected 95% CL exclusion limit on the Standard Model Higgs Boson production rate

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Higgs production rate (see figure 3 (right)) and thus the excess is compatible with the hypothesis of the presence of the Standard Model Higgs Boson.

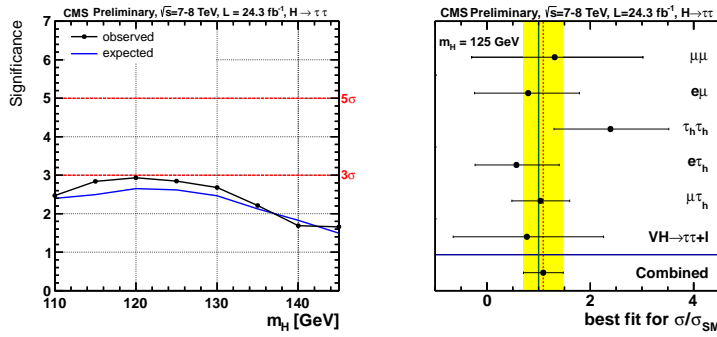


Fig. 3. Observed and expected p-values as a function of m_H . Right: Best-fit signal strength at $m_H = 125$ GeV/c relative to the standard model expectation.

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